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ANALYSIS OF THE RIGIDITY OF OSTEOSYNTHESIS OF THE PROPOSED WIRE-ROD APPARATUS

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ABSTRACT Was proposed wire-rod apparatus (PWRA) for arthrodesis of the knee joint (AKJ). Objective conduct mechanical tests of PWRA to determine rigidity of osteosynthesis (RO) and make a comparative analysis. To evaluate RO of PWRA comparative mechanical tests were carried out for the devices. PWRA was tested in two different assemblies. The tests were performed according to medical technological guidelines as outlined in "Technique for testing rigidity of transosseous osteosynthesis during preoperative planning". Rigidity of the frames were tested longitudinally (distraction and compression) twice, total, 4 times; in frontal, sagittal and transverse planes twice for each of 2 constructs, total 6 times. Statistical analysis was produced with MedCalc software for Windows (version 12.7.8.0) using Mann-Whitney test (independent samples). Comparative analysis of the findings showed differences in RO between PWRA-I and PWRA-II. The findings showed that the increase in the distance between fixation of the rod and rings of resulted in increase in RO.

Keywords: stiffness coefficients, rigidity of osteosynthesis, Ilizarov apparatus, external fixation apparatus, wire-rod apparatus.

AMS Subject Classification: 05B30.

1. Introduction

Extrenal fixation devices (EFD) are widely used in current trauma and orthopaedic practice [9, 10, 14, 23, 24]. Successful result is known EFD to involve stable fixation that can be easily controlled [1, 2] and allow for early functional weight-bearing providing comfortable conditions for a patient [4, 5]. With advances in trauma and orthopedics the Ilizarov method is constantly improved, new EFD [8, 9]. Special mechanical and biomechanical tests are devised by researchers to examine RO of EFD [10, 18].

RO to be provided by an EFD is one of the most important characteristics [14, 19, 22, 25]. Multiple bench and biomechanical tests of RO of original Ilizarov assemblies and half-pins, combined wire-and-half-pin constructs allow for identifying most effective frames [3, 13, 14, 22].

We decided to improve the apparat and offered to use ¾ of Ilizarov half-rings instead of full rings (Registered rationalization proposal June 18, 2015, Certificate No. 4). This design was not found in the affordable literature when applied for AKJ and mechanical testing was needed to examine RO of the construct. Objective conduct mechanical tests of to determine rigidity of osteosynthesis (RO) provided by the devices and make a comparative analysis.

2. Material and Methods

Mechanical testing on request of Azerbaijan Research Institute of Traumatology and Orthopedics was conducted at Mechanical Experimental Laboratory, Ministry of the Defence Industry, Republic of Azerbaijan, Sharg Manufacturing Group and IGLIM Research, Development and Production.

Rigidity tests of EFD were performed according to medical technological guidelines as described in “Technique for testing rigidity of transosseous osteosynthesis during preoperative planning” [10].

The experiment conducted under Guidelines of Technique for Unified Specification of Transosseous Osteosynthesis [20] examined both types of the frames assembled according the diagrams as shown below:

$$\frac{\text{VI,9,90; VII,2-8, VII,4-10}}{\text{¾ 180}}\ \text{---}\ \frac{\text{I,2-8; I,10-4; II,2,90}}{\text{¾ 180}}$$

The diameter of rings measured 180 mm, distance between the rings was 155±5 mm, diameter of wires was 2 mm, diameter of threaded rods was 6 mm.

Our experiment involved the technology used to explore rigidity of osteosynthesis with EFD offered by other authors [6, 7]. A wooden cylinder of 400 ± 5 mm with a diameter of 30 ± 5 mm was used as a substitute of a bone (Fig. 1).

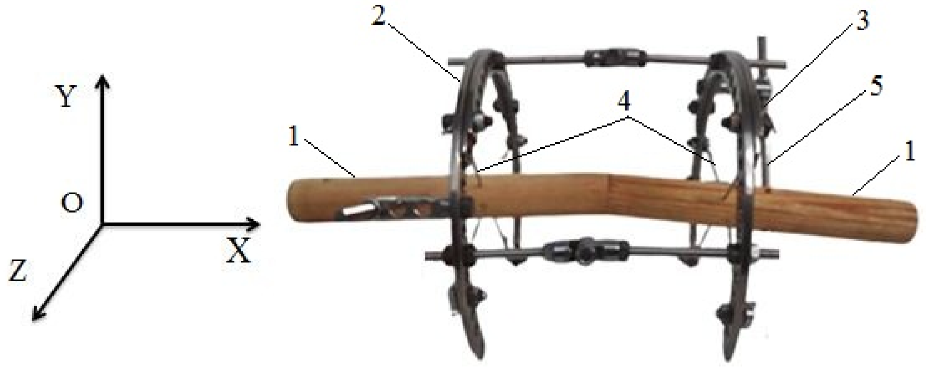
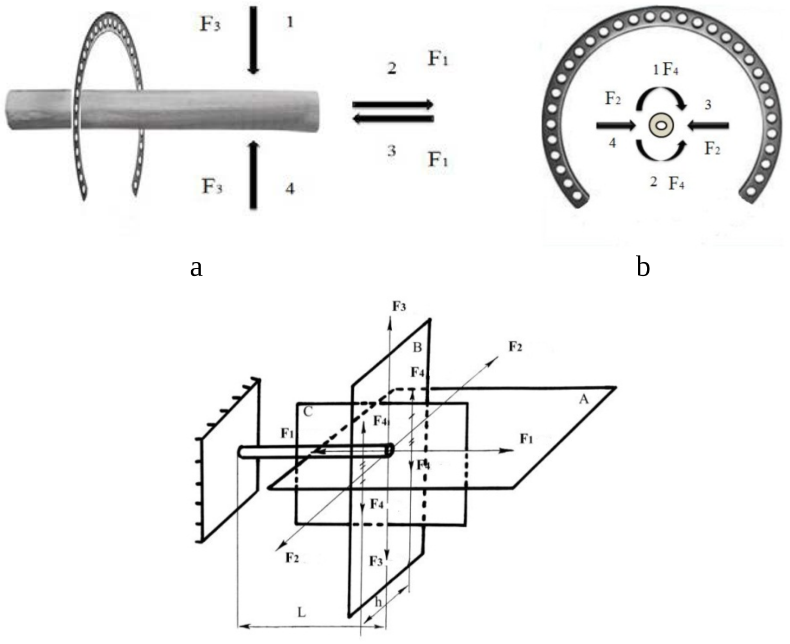


__Fig. 1.__ The proposed wire-rod apparatus: 1 – bone stimulator, 2 – proximal ¾ of a ring, 3 – distal ¾ of a ring, 4 – wire, 5 – rod

Two different assemblies were mounted PWRA-I and PWRA-II. The difference in the constructs included a different distance between connecting rod and ¾ of a ring. According to the scheme the rods placed perpendicularly to the bone were attached to ¾ of the ring using a one-hole post of PWRA-I and three-hole post of PWRA-II.

RO was determined in accordance with medical technology of examining rigidity with transosseous osteosynthesis [15, 17, 20, 23]. The technology is performed with algorithm of standard actions and calculations of determining major characteristics of rigidity with EFD (Fig. 2).

- Axial loading (F_1) defined longitudinal stability of osteosynthesis in distraction and compression. Loads $F_{1distr.}$ and $F_{1compr.}$ are exerted at the longitudinal axis of a simulated bone
- Transverse loads in frontal (F_2) and sagittal (F_3) planes defined transverse rigidity of osteosynthesis: in coronal plane simulating abduction and adduction (loads $F_{2\ abduction.}$ and $F_{2\ adduction}$), in sagittal plane simulating flexion and extension of the limb (loads $F_{3\ flex.}$ and $F_{3\ exten.}$)
- Rotational load (F_4) defined rotational rigidity of osteosynthesis simulating internal and external rotation of the limb ($F_{4\ exterl.}$ and $F_{4\ intern.}$)



a b

c

***Fig. 2.** Diagram of experiment:*

(a). direction of resulting loading vector (side view of module): 1 – «flexion» (F_3), 2 – «distraction» (F_1), 3 – «compression» (F_1), 4 – «extension» (F_3); (b). direction of resulting loading vector (inferior view of module): 1 – internal rotation (F_4), 2 – external rotation (F_4), 3 – «abduction» (F_2), 4 – «adduction» (F_2); (c). general diagram of standard shifting loads: A – coronal plane, B – transversal (horizontal) plane, C – sagittal plane. F_1 – longitudinal load to simulate distraction and compression, F_2 – transverse load to simulate abduction and adduction, F_3 – transverse load to simulate flexion and extension, F_4 – rotational load to simulate internal and external torsion

Loading was increased to get displacement of 1 mm at the docking site or a deformity of 1° and then stopped.

There were total 20 series of experiments conducted at stands R-20 («ZIP», № 2357, GOST 7855-74), MIP-100-2 («ZIP», № 171) and TIP RV 12 (№ 2046).

There was a notion of “stiffness coefficient” (K) used in the experiment and defined as a ratio between external loads and linear and angulation displacement. The more the rigidity coefficient the greater was rigidity of bone fixation [18, 21]. For instance, the rigidity coefficient of distraction and compression was calculated as follows:

$$\boxed{\begin{array}{l} K_{distr.} = F_{distr}/U_{distr.} \\ K_{compr.} = F_{1compr.}/U_{compr.} \end{array}}$$

Where $U_{distr.}$ and $U_{compr.}$ are displacement of fragments in axial direction during distraction and compression, correspondingly.

When conducting mechanical tests there was no need to determine a displacement value that resulted in a deformity or breakage of EFD because this information is not practically important in practice of EFD application and osteosynthesis [22].

Statistical analysis of mechanical tests were made using MedCalc software for Windows (version 12.7.8.0) and Mann-Whitney test (independent samples). A common medical criterion $P<0,05$ was used to provide statistical significance [24].

3. Results

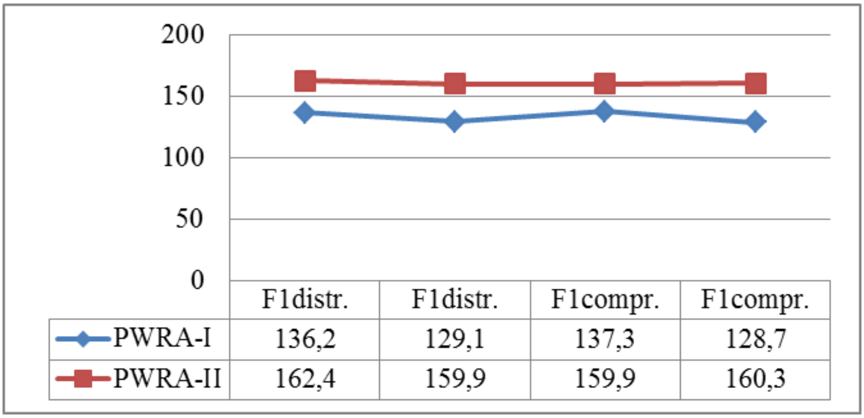
The results of studies with RO of PWRA-I and PWRA-II are summarized in Table 1 and Figures 3 and 4.

The results showed that the best longitudinal rigidity of osteosynthesis could be provided by PWRA-II during distraction, and the worst by PWRA-I. The difference between the values measured 28,5 N/mm (Tab. 1, Fig. 3).

Similar findings were observed in longitudinal compression with the difference of 27,1 N/mm (Tab. 1, Fig. 3).

	PWRA-I	**PWRA-II**
Longitudinal rigidity of osteosynthesis, distraction, N/mm	132,7±3,55	161,2±1,25
Longitudinal rigidity of osteosynthesis, compression, N/mm	133,0±4,30	160,1±0,2
Coronal plane, N×mm/degr	12,2±0,25	12,7±0,1
Sagittal plane, N×mm/degr	26,1±0,2	26,6±0,25
Transversal plane (rotation), N×mm/degr	19,1±0,3	19,6±0,35

***Tab. 1.** Comparative characteristics of RO with PWRA-I and PWRA-II devices*



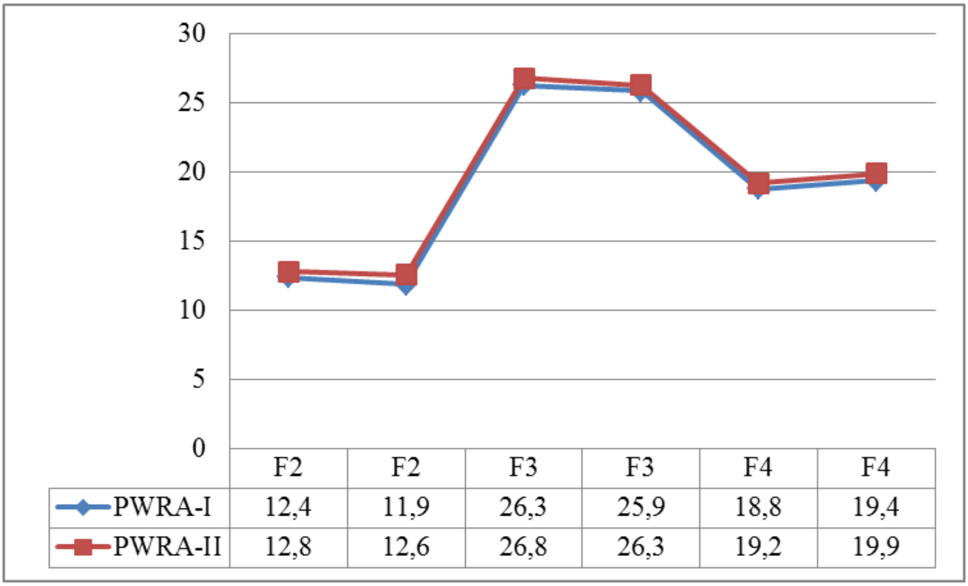
	F1distr.	F1distr.	F1compr.	F1compr.
PWRA-I	136,2	129,1	137,3	128,7
PWRA-II	162,4	159,9	159,9	160,3

***Fig. 3.** RO with loads (F 1) applied longitudinally (simulated distraction and fixation)*

Maximum values in coronal plane were shown with PWRA-II and minimum values with PWRA-I, with the difference of 0.5 N×mm/degr (Tab. 1, Fig. 4).

Similar findings were observed with loads applied in sagittal plane with the difference of 0.5 N×mm/degr (Tab. 1, Fig. 4).

Similar findings were observed with loads applied in transverse plane with the difference of 0.5 N×mm/degr (Tab. 1, Fig. 4).



	F2	F2	F3	F3	F4	F4
◆ PWRA-I	12,4	11,9	26,3	25,9	18,8	19,4
■ PWRA-II	12,8	12,6	26,8	26,3	19,2	19,9

Fig. 4. *RO values with loads applied in different planes (simulated loads in coronal (F 2), sagittal (F 3) and transverse (horizontal) (torsion) (F 4)) planes*

The most considerable difference between PWRA-I and PWRA-II was observed in longitudinal distraction, and minimal difference was shown in coronal, sagittal and transverse plane (Tab. 1 and Fig. 3, 4).

4. Conclusions

- Comparative analysis of the findings showed differences in RO between PWRA-I and PWRA-II.
- The results showed that PWRA-I provided less RO.
- The findings showed that the increase in the distance between fixation of the rod and rings of resulted in increase in RO.

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